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Production Research Report No. 31

A GUIDE TO
intensive
coffee
culture

U.S. DEPARTMENT OF AGRICULTURE



A GUIDE TO

INTENSIVE COFFEE CULTURE

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UNITED STATES DEPARTMENT OF AGRICULTURE

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A GUIDE TO INTENSIVE COFFEE CULTURE

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The United States imports well over \$1 billion worth of coffee annually and therefore is intensely interested in practices that affect coffee production. Within territorial United States, Puerto Rico is the major domestic area that produces coffee. However, yields there are extremely low. In 1956-57 the average yield on 176,000 acres was only 150 pounds of coffee per acre—about enough to supply the Island's population.

From 1952 to 1959 studies were conducted in Puerto Rico aimed at increasing the coffee-yield potential of the island in order to place it in a position to compete on the world coffee market. Substituting sun-grown or light-shade-grown coffee for conventional shade-grown coffee, close planting in rows, heavy fertilization and systematic pruning, and pest control with high-yielding varieties is the key to increasing this potential.

By the intensive method described herein, growing coffee on suitable lands should result in yields approximating 1,500 pounds of high-quality market coffee per acre. Recommendations are based to a large extent on experiments conducted in Puerto Rico, by the authors and on their repeated observations and practical experience, along with principles and results obtained under similar conditions in other countries. Methods described in this report should have wide application in other countries where coffee is grown.

CONDITIONS UNDER WHICH STUDIES WERE CONDUCTED IN PUERTO RICO

Coffee plantations generally consist of old, unselected trees growing under a dense shade provided by old, often diseased trees. Insects and diseases are not controlled; the coffee trees are rarely pruned; and little fertilizer was applied until recently (fig. 1).

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FIGURE 1.—A coffee plantation in Puerto Rico producing about 150 pounds of market coffee per acre. Note spindly growth of trees under dense shade. The denuded lateral branches attest to repeated defoliations by insects and diseases. Owing to lack of pruning, the bearing area is limited mostly to the two or three nodes at the ends of the long branches.

Moreover, occasional hurricanes cause considerable damage to the coffee plantation. There are about 25,000 coffee farms in Puerto Rico, over 80 percent of which are operated by their owners. About a third of the acreage is in several hundred large farms. Normal employment in the coffee industry is about 24,000 persons, with a peak of about 48,000 during the harvest season.

The area best suited to the production of coffee is in the central and west-central region of the island, where elevations range from about 1,000 to 3,000 feet above sea level. The topography is very rugged (fig. 2), with slopes averaging about 50 percent. The climate is excellent for coffee production, with mean monthly temperatures ranging from 67° to 80° F., and rainfall between 70 and 100 inches, fairly well distributed throughout the year. Most of these lands are deep, red, porous, acid soils of the Catalina, Cialitos, Alonso, and Los Guineos series. Their organic matter content ranges between 3 and 6 percent, while their pH value ranges between 4.0 and 5.5. Volume weight of the soil varies from about 1.0 to 1.2. All these soils have the excellent structure, high permeability, and excellent aeration so essential to coffee. Although the nutrient content of these soils is usually low, it can be built up readily by proper fertilization and management.



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FIGURE 2.—Typical view in the coffee region of Puerto Rico. Note the steep slopes that must be protected to safeguard the island's vital hydroelectric resources. Coffee beans in the foreground are being dried in the sun. Trees in the background are used as shade for the coffee.

About a quarter of a million acres in this region are capable of producing high yields of coffee. Moreover, these lands require protection against erosion. The protection against soil and water losses afforded by properly managed coffee plantations is shown in table 1. Because coffee production does not lend itself to extensive mechanization, steepness of slope is not a serious impediment.

THE COFFEE TREE

Coffea arabica, the species of coffee with which this bulletin deals, is grown under a wide variety of conditions in the cooler regions of the Tropics. It is grown under widely varying intensities of sunlight, at elevations ranging from sea level to over 6,000 feet, in areas where annual rainfall may be as low as 30 inches, or, at the other extreme, in excess of 150 inches, on deep soils and on soils where the bedrock is only a few inches below the surface, and on soils with pH values ranging from 3.5 to 7.0.

TABLE 1.—*Effect of various types of cover on soil and water losses from typical, steep coffee soils of Puerto Rico*

Cover	Yearly soil losses per acre	Yearly water losses per acre
	<i>Tons</i>	<i>Inches</i>
Fallow.....	126.0	26.0
Good crop rotation.....	18.0	5.0
Grasses.....	1.0	7.8
Tropical kudzu.....	.2	1.3
Coffee without ground cover.....	33.0	10.7
Coffee with ground cover.....	1.6	2.6

Coffee does best on deep, well-drained, porous, acid soils where the annual rainfall is about 80 inches and the mean temperatures range from 60° to 75° F. These favorable conditions prevail over most of the coffee region of Puerto Rico.

Although coffee has a taproot, it is rarely more than 2 feet in length. Most of the roots are in the upper foot of soil. Indications are that the greatest growth of roots occurs previous to the flush of top growth in the spring.

The coffee tree is a deciduous evergreen, and lost leaves are never replaced.

The coffee plant produces two kinds of branches—verticals and laterals (fig. 1). The laterals are produced in pairs in the leaf axils of the vertical stems and, if cut off, new ones cannot develop in their place. Buds in the leaf axils of primary laterals develop into secondary laterals. Similarly, tertiary laterals may develop on the secondaries.

During the early growth of a vertical, the development of other verticals is inhibited by the terminal bud. Once the terminal growth of a vertical has about ceased or if the plant is bent over, several verticals tend to develop along the stem, the lower ones generally being the most vigorous, growing as much as 5 feet in a year. If the terminal bud is removed before the vertical shoot has lost its vigor, two side verticals develop close to the top.

The flower buds of coffee develop in the leaf axils of the lateral branches. Those of Bourbon, a variety of *C. arabica*, are shown in figure 3, A. In Puerto Rico, coffee flowers several times during the spring. The heaviest flowering usually follows the first rains that come after the rather dry winter season. *C. arabica* is over 90 percent self-pollinated. Insects do not play an important role in pollination.

A well-defined dry period followed by a brief rainy one is ideal for maximum flowering. Usually, about 50 percent of the flowers set, but only 25 percent produce mature berries. Once the fruit is set, moderate rainfall is required for best development of the berries.

The primary lateral branches of coffee bear more heavily (fig. 3, B) and produce larger berries than the secondaries. It is also



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FIGURE 3.—*Coffea arabica* of the Bourbon variety growing in full sunlight with the recommended intensive culture under typical conditions in the coffee region: A, Flowering heavily 2 years after being transplanted to the field; B, heavily bearing, 4 year-old trees.

easier to pick the berries from the primary laterals. Since fruit is generally produced at each node only once, management should be concerned with producing a large area of new, healthy primaries each year.

The coffee crop is borne mainly on the branches produced during the previous year. Thus, growth made during one growing season determines the size of the subsequent crop. Although rainfall is fairly well distributed in Puerto Rico and coffee grows throughout the year, the greatest flush of growth follows flowering during the season when the trees are also producing a crop of berries. Since the trees generally cannot make vigorous vegetative growth when a heavy crop is being produced, the following crop will be smaller. Conversely, when a small crop is borne the trees may produce much bearing wood, which results in a heavy crop the following year if climatic conditions are favorable. This partly explains the marked fluctuations in coffee yields occurring from one year to another.

Yields generally increase until the coffee trees are about 7 years old, when they begin to level off. After the trees reach about 15 years of age, yields may drop off slowly, although the trees may continue to bear heavily for 40 years or more.

Well-established coffee trees rarely wilt and can resist prolonged droughts. However, dry weather when the trees are bearing a large crop can cause considerable drop and berries may not fill out well. During severe droughts young trees may wilt, leaves turn yellow and drop, and some young branches may die back. Plantations of weak-rooted Bourbon bearing their first crop seem to be particularly susceptible. Heavy soils, exposed windy sites, weeds, and improper care of the plantations aggravate the damage. However, most of the trees recover quickly after it starts to rain. Coffee has a low transpiration rate as indicated by its high leaf temperatures.

Experiments in Costa Rica have shown that, although coffee can be grown well under shade, it is morphologically and physiologically suited to being grown in full sunlight and is not by nature a shade-loving plant.

Coffee may be propagated from seed, cuttings, or by grafting. However, as discussed later, only propagation from seed is of commercial importance. Since *arabica* is largely self-pollinated, the seed generally breed true. Asexual propagation is often used for experimental purposes, however.

Coffee can be propagated readily from cuttings, but the method is somewhat complicated and the advantages to be derived are limited. Only vertically growing young material (suckers) should be used. The first three nodes from the ends of the branches are the most desirable. A node with about 2 inches of stem bearing two leaves is best. The cuttings should be treated with indole butyric acid at a concentration of about 4,000 p.p.m., in 50-percent alcohol. Other hormones may also be used. The cuttings should be rooted in sand or vermiculite in a glass box where relative humidity is main-

tained close to 100 percent. It is usually necessary to spray the cuttings periodically with a copper solution to control fungi. A 3-month period is sufficient to produce good rooting. Some success has also been obtained by planting hormone-treated hardwood cuttings of vertical growth directly in the field.

Most methods of grafting can be employed successfully with coffee, but budding is generally less desirable. With the help of propagating bins, two cuttings (each bearing at least one leaf) may be grafted together while the one that is to serve as a stock is rooting. It should be remembered that some species of coffee are incompatible, and that only scions from vertical stems having a terminal growing point will produce a main vertical stem. Other material produces only lateral growth.

COFFEE VARIETIES

Coffea arabica is the most widely planted species and produces the bulk of the world's coffee. The product (termed "milds" by the trade) is of the best quality and brings the highest prices. This rather low-growing species yields heavily when properly managed and is used almost exclusively in Puerto Rico and Latin America.

There are many other recognized species of *Coffea*—*liberica*, *excelsa* or *dewevrei*, and "Robusta" or *canephora* being the most important. These species are grown mostly in Africa and the East and produce lower priced, "hard" coffee, which has recently found a good market as blends in the powdered concentrate industry.

C. liberica is a large tree with berries and leaves larger than those of any other species of coffee. *C. excelsa* is a very large tree producing berries of about the same size as *arabica*. The cost of harvesting and processing the crop of the two species is much higher than that of *arabica*, owing to the height of the trees and difficulties in processing the beans, and because both species bear over much of the year in Puerto Rico.

Robusta coffee has characteristics somewhere between those of *excelsa* and *arabica*. Many varieties of Robusta are grown in Africa and the East, where their resistance to the rust called hemileia disease is of great value. Should this disease spread to Puerto Rico, or should a good local market develop for hard coffees, limited plantings of Robusta might be warranted. This species, which produces "hard" coffee, is generally self-sterile, can be trained to grow rather low, bears during only one season of the year, and the berries are relatively easy to process, although rather small.

To produce high yields of good-quality coffee for the world market, *arabica* should be preferred.

Common, or "Typica" (fig. 4), is the most widely used variety of *arabica* and is grown almost exclusively in Puerto Rico. Several local selections of this variety appear promising.



FIGURE 4.—Three-year-old intensively managed commercial planting of the Tipica variety at Adjuntas. Shade was removed 2 years after planting. Note natural cover between rows which protects soil from erosion.

Caturra (fig. 5) is a very promising, vigorous, precocious, high-yielding, semidwarf variety with rather large, dark green leaves. Picking and pruning are easy because of its low growth habit, which, together with its strong stem and root system, should make it resistant to damage by hurricanes. Villalobos is another semidwarf variety.

Bourbon (figs. 3 and 6) is a precocious, high-yielding variety, distinguished by the rather upright growth of the young lateral branches and the generally green color of the very young leaves compared with the bronze-colored tips of Tipica.

Mundo Novo (fig. 7) is a promising, strong-rooted, pest-resistant variety recently introduced into Puerto Rico from Brazil. Columnaris is a rather tall-growing, late-maturing variety grown commercially to some extent in Puerto Rico.

Local information on the performance of these varieties grown under intensive culture is limited. In four separate experiments by the authors at Castaner, P.R., Bourbon coffee produced very high yields starting only 3 years after being transplanted (table 2). The plantations are in excellent condition and give every indication of continuing to bear heavily for many years.

The intensively managed, commercial planting of Tipica shown in figure 4 was transplanted in 1954 and produced its first large crop of about 1,200 pounds of market coffee per acre in 1957 and 1,500 pounds in 1958.



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FIGURE 5.—Intensively managed 2-year-old planting of Caturra—a semidwarf variety of *arabica*—near Aguas Buenas. Note low, sturdy growth habit and heavy crop.

TABLE 2.—Yields of market coffee produced over a 3-year period by intensively managed plantings of the Bourbon variety. All values are averages of at least 300 trees

Experiment and year	Age of plantation ¹	Yields of market coffee per acre
P.R.-9:	<i>Years</i>	<i>Pounds</i>
1956-----	5	2, 270
1957-----	6	1, 640
1958-----	7	1, 700
P.R.-8(a):		
1956-----	3	2, 070
1957-----	4	1, 430
1958-----	5	1, 694
P.R.-8(b):		
1956-----	2	570
1957-----	3	1, 785
1958-----	4	1, 747
P.R.-19:		
1957-----	3	1, 840
1958-----	4	1, 250

¹ Years from transplanting.



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FIGURE 6.—Mature plantation of the Bourbon variety growing in full sunlight with all the intensive management practices carried out in the proper manner. This experimental planting has yielded an average of about a ton of market coffee per acre yearly during the past 3 years. Note heavy crop accompanied by strong, healthy, vegetative development which assures a good crop the following year.

The very promising Caturra variety is developing well and bearing heavily under intensive management in a small commercial planting (fig. 5) on another private farm. This planting, after going through a record drought, yielded about 1,500 pounds of market coffee per acre only 2 years after transplanting to the field.

The Columnaris variety, 3½ years after planting, has yielded little, although developing well in the authors' experiments. Young plantings of Mundo Novo are thriving at two locations (fig. 7).

The Soil Conservation Service and the Agricultural Research Service in cooperation with private farmers are carrying out field trials to determine the performance of nine varieties of coffee at various locations in the coffee region. To date, the Caturra and Mundo Novo varieties, in addition to the Bourbon, appear very promising. These three varieties bear heavily at an early age.

From the above it appears that the Tipica, Bourbon, Caturra, and Mundo Novo varieties are adapted to the recommended intensive management. Although these varieties or others may prove to be superior, to date only the Bourbon variety has definitely proved its worth. This evidence corroborates that obtained elsewhere in Latin America, where the Bourbon variety is displacing Tipica by virtue of its higher yielding qualities.



FIGURE 7.—Plantings of the Mundo Novo variety 18 months old growing under intensive management near Aguas Buenas. Note intercropping with plantains—a type of cooking banana.

The main disadvantages of the Bourbon variety are its tendency to overbear if not managed carefully, the rather small size of the beans, and its weak root system during the first 2 or 3 years after transplanting.

PRODUCTION OF SEEDLINGS

The production of healthy, vigorous seedlings from superior trees is the first step towards a high-yielding coffee plantation. The methods described below were tested on a large scale and resulted in the production of healthy seedlings ready for transplanting only 10 months after seeding, compared with about 16 months required with the methods commonly used on the island.

Only seed from healthy, vigorous plants with a record of sustained high production should be used. The berries should be picked when ripe and all small or diseased ones discarded. The pulp should be carefully removed so as to avoid breaking the parchment. The beans should then be washed to remove the mucilage and planted immediately. If they are to be stored, they should be spread out to dry in the air for about 10 days. Coffee beans should never be allowed to remain in bags or piles unless completely dry, as they will heat up rapidly and lose their viability.

Even well-dried seed should not be stored for long periods, since they lose their viability rapidly after the first few months. One pound of seed should produce at least a thousand healthy seedlings or nearly enough to plant 1 acre.

Seedbeds should be located as near as practical to the fields to be planted. A deep friable soil on a gentle slope near a source of water is ideal. If the pH of the soil is less than 5.0, 1 ton of limestone containing some magnesium should be applied per acre. The soil should also be treated with an aqueous solution of aldrin at the rate of 2 pounds of the technical material (1 gallon of emulsifiable concentrate containing 2 pounds of aldrin in 50 gallons of water) per acre to kill white grubs, cutworms, and other soil insects. A pint of the commercial aldrin mixed with 5 gallons of water is enough to treat an area 5,000 feet square when sprayed on the soil with a knapsack sprayer.

The land should then be plowed several times or the soil worked with a hoe to a depth of at least 6 inches until it is well pulverized. Ditches or walks should be constructed about every 6 feet on the contour to provide drainage and a place to walk.

Artificial shade should be used whenever possible, since shade trees compete with the seedlings and retard their development. Shade may be provided by cheesecloth or by chicken wire covered with banana leaves or grass, or simply by a wire frame covered with palm leaves. The shade may be about 3 feet high and cover only the beds to permit walking upright between them, or the entire area may be covered at a height of 6 feet or more. If artificial shade cannot be provided, small trees, plantains, or bananas may be used, since the amount of shade they provide can be readily controlled.

The seeds may be germinated close together in small seedbeds. After seeding to a depth of about one-half inch the ground should be covered with banana leaves or grass to conserve moisture and reduce weed growth. Frequent watering is often necessary. This cover must be removed when the seedlings start to emerge about 6 weeks after planting. Seedlings should be transplanted to a seedbed before they have three pairs of leaves and preferably as soon as the first pair appears. The seedlings are planted 1 foot apart in rows 18 inches apart, or about 25,000 seedlings per acre. Care should be taken not to bend the roots when the seedlings are set out. Although this system reduces weeding costs considerably, there is less risk in planting the seed directly in larger beds.

About a month after transplanting, 1 level tablespoonful of a 10-10-10 fertilizer should be applied in a small hole about 2 inches to the side of each plant and covered with soil. A full tablespoonful of fertilizer should be applied to alternate sides of the plants every 2 months thereafter. Urea at the rate of 4 pounds in 50 gallons of water may be used as a foliar spray to further speed the development of the seedlings. The seedbeds should be carefully weeded so as not to injure the roots or stems of the seedlings.

The leaves must be protected from damage at all times, since loss of even a few retards the development of the seedlings. When the first pair of leaves appears, the plants should be sprayed with the mixture described later (p. 39) for control of insects and diseases. The treatment should be repeated about every 2 months or whenever damage to the leaves or the presence of scale insects is noticed. Snails sometimes destroy small coffee seedlings and should be controlled with poison bait as discussed later. If the seedlings are attacked by wilt, it may be controlled as discussed in the chapter dealing with diseases. The copper in the recommended spray will help to prevent wilt.

Some seedlings may become yellow owing to a deficiency of iron, but their growth is not greatly reduced unless the deficiency is severe, in which case the use of a few grams of a chelated iron compound per plant is recommended.

The seedlings are transplanted when 1 to 2 feet tall. Spring plantings should be set out before the flush of growth starts and weakens the trees. All weak, diseased, small or malformed seedlings should be discarded. The seedlings should be dug up carefully with a ball of earth at least 6 inches in diameter and 8 inches deep surrounding the roots. The ball of earth can be wound lightly in burlap and the seedlings placed in boxes for transporting to the field.

Coffee seedlings should be grown in containers whenever possible. The big advantage of this system is the ease with which the seedlings can be transplanted to the field and the almost perfect survival rate. However, if containers are used, facilities for watering must be available and the seedlings must be transplanted before they are too large and become root bound.

Polyethylene bags perforated on sides and bottom are very desirable containers. They should be filled with fertile, friable soil, which should be allowed to settle before planting. They are available locally in any desired quantity at about a cent a piece.

Containers left open at both ends may be constructed from tar paper at low cost. If oil cans are used, they should be washed with water and a detergent, perforated to permit drainage, and the bottoms partly cut through to facilitate removal when the seedlings are set out.

ESTABLISHMENT OF PLANTATION

Very exposed sites with constant strong winds should not be planted to coffee. If it is necessary to plant coffee in such areas, properly spaced windbreaks of adapted species and shade trees should be used.

If the area is wooded, the first step is to clear the land of all large trees. They may be killed by nicking or girdling and then painting or spraying with a mixture of 1 pound of 2,4,5-T (2,4,5 trichlorophenoxyacetic acid) in 5 gallons of diesel oil. If shade is to be used, sufficient young, well-spaced trees of desirable species (Ingas, etc.)

may be left to provide a very light shade. All old coffee trees should be destroyed.

The need for careful planning and layout of the plantation to assure efficient operation must be emphasized. The location of farm roads, processing facilities, fences, and water-supply and water-disposal systems all require careful thought and planning. Contour paths through which a jeep can be driven should be built at about 200-foot intervals, supplemented by narrow walks at shorter intervals throughout the plantation. These paths will be of help in distributing fertilizer and lime, in harvesting operations and in spraying.

Plantains or bananas may be grown between every other row of coffee for the first 2 years or so. In this way the land between the rows is utilized until the coffee is large enough to take over. Weeding costs are reduced, the coffee is given some protection while it is becoming established, and a considerable profit can be made from the sale of the plantains or bananas.

High plant populations become possible by doing away with most or all of the shade trees and fertilizing heavily. Planting the coffee trees close together in rows has many advantages. Few weeds grow under the densely shaded rows, and it is easy to mow or use herbicides between the rows without harming the coffee. Moreover, a cover crop can be grown there to keep the soil cool and protected, while the shade of the coffee trees has the same effect in the rows. Spraying and care of the trees is greatly facilitated by growing them in rows.

The authors have found it undesirable to grow two or three rows of coffee close together to form a hedge. It is difficult to spray and prune the trees and to harvest berries from the inside branches. Furthermore, the dense growth discourages suckers and those that develop are elongated and very weak.

It is recommended that the coffee trees be planted in contour rows about 10 feet apart, with the plants spaced from 3 to 4 feet apart in the rows (fig. 8). About 1,300 trees are required per acre with this system.

The health and yields of coffee trees in later years are strongly influenced by their initial treatment. Thus, special care in establishing the trees appears well warranted.

The coffee seedlings should be planted in holes about 18 inches square and 12 inches deep, since large holes accelerate the development of coffee during the first critical years. A laborer can dig about 100 holes of this size daily. In some cases the strips where the holes are to be dug may be plowed several times to reduce the cost of holing. Herbicides should be applied in these strips before the coffee is planted to retard weed growth.

About 2 pounds of limestone containing magnesium should be mixed with the soil from each hole and about half a pound of 20-percent superphosphate placed at the bottom of each hole and covered with soil. Both lime and phosphates, when applied to the surface, do not move much into the soil and this opportunity for deep placement should not be overlooked.



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FIGURE 8.—Young commercial plantation grown with the recommended intensive management practices. Note contour rows with strip of low-growing grass between and temporary intercropping with plantains.

The holes and the loose earth to be used in filling them should be sprayed with aldrin before the seedlings are transplanted to protect them from soil insects. One quart of the commercial aldrin (p. 38) diluted with water to 5 gallons is sufficient to treat about 400 holes with a knapsack sprayer.

The seedlings should be planted at the same depth that they grow in the seedbed. It has been found that yields are reduced for many years if the seedlings are planted too deep. They may be planted at a slight angle to encourage the early formation of suckers and thus expedite conversion to a multiple-stem system of pruning. The soil should be firmed around the ball of earth surrounding the seedlings, but care should be taken not to press down on the ball itself so as to avoid breaking it and thus severing the coffee roots. When leaves, grass, or other trash are available, they may be used as a mulch on the ground around the seedlings. However, if snails abound it may be necessary to use poison bait repeatedly, since these pests thrive under a mulch and will gnaw the stems and eat the leaves of seedlings.

The plants should be watered, if there is no rain during the first 4 or 5 days after transplanting, particularly if the weather is hot and dry. This work is not very expensive compared with the investment in coffee plants and will take much of the risk out of transplanting.

If shade is used, bare root plantings may be successful. It is best to use rather small seedlings and to dig them up carefully, with as much of the roots as possible. The roots should be protected with wet burlap or other material and the seedlings planted as soon as possible. They should be set out carefully in the holes so that the roots are not bent, and soil pressed down around them.

One month after transplanting, all dead or weak seedlings should be replaced and about 3 ounces (a small handful) of a 10-10-10 fertilizer spread on the ground around each seedling, starting about 4 inches from the trunk and extending as far as the tips of the lateral branches. This treatment should be repeated every 3 months during the first year. During the second year the amount of fertilizer should be increased to 4 ounces per plant every 3 months. During subsequent years the fertilizer recommendations for mature trees should be followed. Young coffee trees may be severely defoliated if too heavily fertilized during dry weather but usually recover quickly.

The young seedlings should be sprayed immediately with the recommended pesticide mixture whenever leaf spots or scale insects are noted, since damage to leaves or their loss will set the trees back seriously at this critical time. It is usually best to spray about every 3 months during the first year or so.

A strip about 4 feet wide—2 feet on each side of the rows of coffee—should be weeded frequently. In young plantations it is usually necessary to weed about five times yearly. Care should be taken not to hoe deep, since coffee is shallow rooted. The remaining area should be mowed with machetes to a height of about 4 inches to maintain proper ground cover for erosion control. Use of a leguminous cover crop (fig. 9) between the rows of coffee is recommended.

All coffee trees not doing well about 3 months after transplanting should be replaced with vigorous, healthy seedlings. Young healthy coffee trees about 1 year after planting are shown in figure 8.

SHADE

Shade trees help to control erosion. They anchor the soil in place, while the leaves accumulating on the surface protect it from the impact of rain drops which dislodge soil particles and seal the surface, thereby increasing runoff and erosion. Shade trees also keep the surface soil cool, whereas bare soil may become hot enough to damage the coffee roots. The trees also help maintain soil organic matter by providing organic material. In addition, shade trees reduce cultivation costs by suppressing weed growth and, since they are leguminous, may fix appreciable quantities of nitrogen from the atmosphere.

As shown later, all these advantages can be attained without shade by planting the coffee trees close together in rows with a leguminous cover crop between the rows. Thus, the question of soil protection



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FIGURE 9.—Cover crop of *Indigofera mucronata* growing between rows of coffee protects the soil and helps to control weeds.

is not very important in determining the need for shade at least in coffee plantations in Puerto Rico.

Shade trees complicate the management of coffee plantations. They must be planted before the coffee and pruned periodically to prevent excessive shading, which reduces coffee yields and causes the trees to grow weak and spindly. Layout of the plantation, spraying, and rehabilitation after a hurricane are made difficult by the presence of shade trees. Furthermore, densely shaded coffee trees may be severely set back by sudden exposure to full sunlight after a hurricane. In addition, the coffee ant which lives in the shade trees is not a problem when coffee is grown in full sunlight.

Since most of the world's coffee is grown in full sunlight, it is not surprising that the experiments in Costa Rica mentioned previously show that coffee is suited by nature for growing without shade. Furthermore, tests there and elsewhere in Latin America have shown that there is no perceptible difference in quality between shaded and sun-grown coffee.

Shade trees reduce yields by robbing the coffee of light, moisture, and nutrients. Average yields produced under typical conditions in the coffee region by intensively managed coffee growing in full sunlight (table 2), were the highest ever obtained in Puerto Rico, and there is every indication that the trees will continue to bear heavily for many years. Furthermore, experiments in various countries and

local observations and experience clearly show that it is impossible to produce high yields of coffee under shade trees that keep out much more than a third of the sunlight.

On the other hand, since densely shaded coffee does not bear heavily, it is more tolerant of careless management than is heavily bearing coffee growing in strong sunlight.

Also, shade can modify climate considerably, making it possible to grow coffee in less favorable environments. Shade trees help keep temperatures low, so that coffee can be grown in areas that would otherwise be too hot for economic production of this crop. By reducing wind movement the trees make it possible to grow coffee on exposed sites. They also protect the soil where other measures are not or cannot be used.

Local experiments illustrate what has been noted above. Years ago an experiment was carried out to determine the effect of artificial shade on the growth and yields of coffee. The trees were planted near the coast where high temperatures prevail and were not properly cared for; i.e., they received little fertilizer and were not protected from pests. The plantings in full sunlight were a failure. The excellent results obtained in the authors' experiments with coffee growing in full sunlight in the cooler coffee region under proper, intensive management, show that the difference lies in environment and proper management.

The degree of shade to use depends on the site and on the capability and willingness of the farmer to care for his plantation properly in exchange for high returns. In summary: (1) Proper conservation can be attained irrespective of shade level; (2) shade trees generally depress yields and complicate the management of plantations; (3) shaded coffee can be grown on less favorable sites, i.e., at lower elevations, on exposed, windy sites, and on poorer soils where plantings in full sunlight might not thrive; and (4) shaded coffee can tolerate mismanagement better than can plantings in full sunlight.

Given proper intensive management of the plantations it seems best to grow coffee in full sunlight or very light shade at elevations of about 2,000 feet or above in the coffee region of Puerto Rico. About 25 percent shade should be used at lower elevations where temperatures are higher, on exposed windy sites, or where full, intensive management is not practiced. About 25 shade trees 8 inches in diameter, or 100 trees 4 inches in diameter, and well spaced are required per acre to provide about 25 percent shade. Plantains or bananas can be used for temporary shade.

The sudden removal of all shade from old coffee plantations may be disastrous, as shown by two experiments conducted by the authors. Although the coffee trees were heavily fertilized and well cared for, they produced only one good crop and then became unthrifty and yielded little. Old coffee trees may gradually become acclimated to strong sunlight, but it is best to start with new plantings and to care for them properly.

It should be emphasized that shading is just one of the practices involved in coffee culture. The other recommended practices for intensive coffee culture are the same whether the plantation is grown in full sunlight or under light shade.

SOIL MANAGEMENT

Cover Crops

Cover crops have reduced coffee yields where the annual rainfall was 50 inches or less and there was a well-defined dry season. Under these conditions the cover crop apparently competes with the coffee trees for the limited moisture available. What effect cover crops may have on coffee yields under the high rainfall conditions of Puerto Rico's coffee region is not yet definitely known. However, since very high yields have been produced by intensively managed coffee with grass or a legume growing between the rows (table 2; figs. 4, 7, 8, and 9), it is apparent that a cover crop will not reduce yields greatly. Furthermore, these plantations bore heavily and came through the worst drought on record in 1957 in good condition.

Excellent soil protection can be attained by planting the coffee trees close together in rows with a good cover between the rows. Cover crops control erosion and reduce water losses from runoff as shown in table 1. Erosion losses under a coffee cover crop probably approximate the very low levels shown for grasses or tropical kudzu in this table. A cover crop will also prevent compaction of the soil surface caused by laborers walking through the plantation in wet weather. On the other hand, the dense, low-growing coffee affords excellent protection to the soil under the rows. Indeed, it may be as well protected as under woodland.

Although the organic-matter content of soil under coffee growing in strong sunlight may eventually be lower than that in densely shaded plantations, it is unlikely that the content will fall below desirable levels. Analyses made by the authors on hundreds of samples of typical coffee soils showed that their organic-matter content rarely falls below 3 percent even after many years of clean cultivation. At this level of organic matter, these soils have an excellent physical condition and an adequate exchange capacity. The soils on which the high yields shown in table 2 were obtained had an organic-matter content ranging between 3 and 4 percent.

The excellent physical condition and adequate exchange capacity of Catalina clay, a typical coffee soil, is illustrated by the data in table 3, which shows the effect of three types of cover on the condition of this soil. The land had been in each type of cover for at least 16 consecutive years.

A study was also made of the effect of various types of cover on temperatures of an Alonso clay soil in the coffee region. Temperatures were taken at a depth of 1 inch at noon on a clear, hot, sunny summer day following a prolonged dry period. As shown in table 4, soil temperatures can be kept low in sun plantings by growing

TABLE 3.—*Effect of 3 types of land use on some properties of the surface 6 inches of a typical coffee soil (Catalina clay) of Puerto Rico. All values are averages of 6 or more samples taken from three adjoining fields*

Soil property	Woodland	Overgrazed native grasses	Sugarcane
Organic matter-----percent--	6. 50	3. 70	4. 50
Nitrogen-----do-----	. 33	. 19	. 23
Exchange capacity----m.e./100 gm. of soil--	19. 10	15. 00	16. 40
Bulk density-----do-----	. 96	1. 22	1. 07
Percolation rate-----inches/hour--	25. 00	11. 70	5. 30
Pores pF 1.78-----percent--	16. 00	9. 30	8. 30
Available water pF 2.7-4.2-----do-----	9. 50	10. 50	8. 80

the trees close together in rows with a cover crop between. Although bare-surfaced soil heated up to 109° F., which is harmful to coffee roots, the soil under the cover crop or coffee rows stayed about as cool as that under densely shaded coffee. Thus, high soil temperatures are not a problem with properly managed sungrown coffee.

Although a leguminous cover crop is desirable between the rows of coffee, natural vegetation can be used. If it is kept cut back, a low, close-growing grass sod will eventually cover the soil between the coffee rows and keep out weeds. This sod should be mowed several times a year. With such a cover the coffee should be provided with sufficient fertilizer over and above any quantities taken up by the grasses. However, at the high fertilizer levels herein recommended, it is unlikely that competition for nutrients by the cover crop is important, particularly since recommendations are based on fertilizer experiments on which a grass cover crop was grown between the rows of coffee.

The ground under the coffee rows should be cultivated periodically until weed growth is prevented by the dense shade of the trees. As

TABLE 4.—*Effect of various types of cover on temperatures of Alonso clay soil in the coffee region of Puerto Rico. All values are averages of 10 measurements taken at a depth of 1 inch*

Cover	Maximum	Minimum	Average
	° F.	° F.	° F.
Bare-surface soil-----	109	102	108
Under shaded coffee trees-----	79	72	75
Under sun-grown coffee:			
Under coffee rows-----	79	74	77
Under grass cover crop-----	84	80	82
Under cover of <i>Indigofera mucronata</i> -----	77	74	75

the trees develop, they gradually shade out the cover crop until only a narrow strip remains between the rows.

The authors have found that the legume *Indigofera mucronata* (fig. 9) is an excellent cover crop to grow between coffee rows. This perennial legume is low growing, does not climb the coffee trees, has no serious pests, and is easily propagated from seed which it produces in abundance. It grows rapidly, suppressing weed growth once it is well established and can fix about 100 pounds of nitrogen per acre yearly from the atmosphere while growing between the rows of coffee.

The seed pods of *mucronata* should be harvested when mature, dried in the sun, beaten, and the seed cleaned by sifting and blowing away the chaff. Several rows of seed should be planted in shallow furrows between the rows of coffee. The seed should be left for rain to cover them with soil, since emergence will be reduced if covered too deeply. The rows should be weeded as required until the legume is well established. *I. mucronata* should not be cut until it covers the ground to a depth of about 18 inches. Thereafter it should be cut back to a height of about 4 inches every year at the start of the dry season. This cutting will reduce use of water by the cover crop, and the cut material can be used as a mulch under the coffee trees further conserving moisture as well as supplying some nitrogen.

Mulches

Coffee yields have been increased by mulching where the annual rainfall was 50 inches or less and there was a marked dry season. Also, soil fertility was almost invariably inadequate in these studies. What effect mulches would have on coffee production in Puerto Rico's mountains is not known. However, it would seem that the beneficial effects of mulches would be minor under the high rainfall conditions of the coffee region with the recommended heavy fertilization and intensive management.

It has been shown in other countries that a mulch must be at least 4 inches thick to be effective. Such a mulch requires about 20 tons of green grass per acre, and additional material must be added at least twice a year to replace that which decomposes. Thus, at least an acre of moderately fertilized grasses is required to provide mulching material for every acre of coffee. Such a practice is not feasible in a country with the limited land resources of Puerto Rico. Furthermore, the cost of cutting, transporting, and applying a mulch on the steep lands of the coffee region is prohibitive.

Fortunately, most of the benefits expected of mulches, i.e., erosion control, low soil temperature, weed control, and preservation of soil organic matter and physical condition, can be obtained practically with a cover crop and management of the coffee plantation as recommended. The nutrients that mulches can supply are provided much more cheaply as fertilizer.

A mulch may be helpful during the first year after transplanting to protect the soil around the coffee trees, and should be used if material is available in the field. The mulch should cover the soil on both sides of the seedlings to a distance of about 2 feet.

Erosion Control

Erosion of the steep coffee lands must be controlled, if high yields are to be produced continuously and siltation of the vital hydroelectric reservoirs prevented.

As mentioned previously, the close-growing, contour rows of coffee with a cover crop between the rows is the best way of controlling erosion. It is frequently necessary to supplement these measures with gully control and with diversion ditches to keep water from higher land and roadside ditches from damaging the plantations.

There are two types of mechanical structures that supposedly increase coffee yields and conserve soil and water—individual terraces and catchment ditches. Individual terraces are small, level benches built around each coffee tree by digging into the slope above it. Catchment ditches, or “minados,” are shallow trenches dug across the slope between the coffee trees and allowed to become filled with trash.

There are no reliable experimental data available regarding the value of these practices either in terms of coffee yields or of soil and water conservation. In the absence of such data the only possible evaluation of these practices is one based on careful observations and analysis.

It is difficult to see how either individual terraces or minados can benefit the coffee trees themselves. The building of an individual terrace around an old coffee tree results in the destruction of about half its root system, while a young tree planted in a previously constructed terrace will be growing largely in subsoil. Although organic matter tends to accumulate on the terraces, the advantages of such a concentration are doubtful, particularly since the coffee roots soon extend well beyond the terraces. As far as minados are concerned, it is difficult to see how the inevitable pruning of the coffee roots and the burying of organic matter can greatly favor the coffee trees. Organic matter left on the surface of the soil is more effective in erosion control than if it is buried.

It is possible that these practices reduce runoff slightly. As a result of bench terracing, about 5,000 square feet of almost level land are produced per acre. This leveling may result in a slight increase in the amount of water infiltrating the soil. Also, the mechanical effect of terraces and minados in slowing down the flow of water over the soil surface may help to increase the infiltration rate slightly. It is calculated that minados can hold about one-quarter of an acre-inch of water over short periods of time. In view of the very high infiltration rates of the coffee soils (table 3), all these considerations are of little importance, however.

Approximately 25 tons of soil are loosened and moved in the process of constructing either individual terraces or minados on 1 acre of land. This soil is highly susceptible to erosion until it settles and is stabilized by vegetation. In addition, a steep, unprotected cut is exposed on the upper side of the terraces.

Individual bench terraces cannot be constructed effectively on slopes in excess of about 45 percent. On steeper lands much of the soil rolls downhill soon after it is dug up. The cost of constructing individual terraces or minados generally comes to about \$25 per acre, a considerable investment.

In view of the lack of experimental evidence proving the value of these costly mechanical practices, and particularly since objective analysis fails to disclose any great apparent advantages, their use is highly questionable and is not recommended.

Weed Control

Weeding is not a serious problem in mature plantations managed as herein recommended. Few weeds grow in the dense shade under the coffee rows, their growth being limited to a narrow strip between the rows.

However, weed control is a major problem during the first couple of years while the coffee becomes well established. Frequent weedings are required during this period.

Although some herbicides are toxic to coffee and with bearing trees it is possible that some of the toxin may enter the beans, making them unfit for human consumption, proper herbicides may be used judiciously.

Since herbicides are most effective on succulent weeds, they should be applied in sprays before the weeds mature but after most of the seed have germinated. Repeating the spray about 1 month later helps to insure good weed control.

The spray should not be applied too near the coffee trees and the nozzle should be pointed away from the plants. The material must be thoroughly mixed and agitated constantly in the spraytank. The person applying the herbicide should be protected by gloves, goggles, and a mask, should bathe thoroughly with soap and water after work, and take all other necessary precautions.

Research has shown that contact herbicides applied in sprays are the most desirable ones under present conditions in the coffee regions. They kill the tops of all prevalent species of weeds, while the roots of certain species remain alive and help to control erosion. However, these roots can be killed by applications repeated at short intervals. Damage to the coffee trees, which is limited to the foliage actually hit by the spray, is avoided by the use of a directional spray applied to the weeds away from the foliage. The effect of the herbicides is apparent within a few hours, and the laborer can "touchup" spots that were missed in the initial application.

Weeds have also been effectively controlled with a commercial mixture of pentachlorophenol [PCP] as an oil emulsion. One and one-half gallons of a 6-percent concentration is added to 3 gallons of water to form a stable oil emulsion. The weed foliage must be thoroughly wetted with this spray mixture.

A knapsack sprayer with a two-nozzle hand boom can be used to treat a strip 6 feet wide conveniently. This is about the width of the area to be treated between the coffee rows. A laborer can spray from 4 to 6 acres of plantation a day, applying about 25 gallons of spray per acre (12½ gallons of the concentrate). From 4 to 6 applications yearly are sufficient to control weeds in plantings 2 or more years of age.

FERTILIZATION

Three concepts should be borne in mind when considering the fertilization of intensively managed coffee. First, since there is limited experimental evidence on the response to fertilization by coffee grown in this manner, considerable reliance must be placed on logical reasoning based on general scientific principles. Second, since the coffee soils of Puerto Rico have a relatively low content of the major plant nutrients in forms available to coffee, fertilization should be guided primarily by the needs of the coffee plant without much consideration to the quantities of nutrients in the soil. Finally, since the high value of the coffee crop makes the cost of fertilization an item of secondary importance, it is best to err on the side of generous fertilizer applications.

Major Elements

Nutrients to produce a 2,000-pound crop of market coffee (about 10,000 pounds of coffee berries) should be provided, since crops of this size will be produced occasionally. Such a crop removes about 80 pounds of nitrogen, 15 pounds of phosphoric acid, and 100 pounds of potash. Additional nutrients are required for vegetative development. It seems reasonable to assume that an acre of fast-growing, high-yielding coffee will take up at least 120 pounds of nitrogen, 30 pounds of phosphoric acid, and 130 pounds of potash yearly.

This ratio of nutrients checks rather well with the experimental evidence obtained by the authors in a detailed fertilizer experiment with intensively managed coffee growing in full sunlight. The experiment was carried out on a steep Alonso clay soil, the upper 6 inches of which have a pH of 4.8, 3.5 percent organic matter and 22 m.e. of exchange capacity, and 12 m.e. of exchangeable bases per 100 grams of soil. Climatic conditions are typical of the coffee region of Puerto Rico. In this experiment, three levels equivalent to 0, 150, and 300 pounds per acre yearly each, of nitrogen (from ammonium sulfate), phosphoric acid (from 20-percent superphosphate), and potash (from potassium chloride) were tested. The levels of each

nutrient were varied in the presence of the highest level of the other 2 for a total of 8 treatments replicated 16 times with 12 trees per plot. The fertilizer was applied in three equal applications yearly. The coffee was grown in rows with a grass cover crop between, and all plots received limestone at the rate of 2 tons per acre. Results of this experiment are summarized in table 5.

TABLE 5.—*The effect of 3 levels each of nitrogen, phosphoric acid, and potash on yields of intensively managed coffee*

Yearly fertilization per acre ¹			Yields of market coffee per acre		
N	P ₂ O ₅	K ₂ O	1956 ²	1957	1958
<i>Pounds</i>	<i>Pounds</i>	<i>Pounds</i>	<i>Pounds</i>	<i>Pounds</i>	<i>Pounds</i>
0	0	0	920	660	560
300	300	300	1,890	1,400	1,890
0	300	300	760	1,050	930
150	300	300	1,630	1,420	1,660
300	300	0	1,370	1,000	1,110
300	300	150	1,940	1,310	1,510
300	0	300	1,390	1,530	1,740
300	150	300	1,810	1,590	1,740
Least significant difference:					
At 5-percent level.....			570	360	360
At 1-percent level.....			770	480	480

¹ In 3 equal applications yearly.

² 7 replications in 1956—16 in successive years with 12 trees per plot.

Yields for the first two crops were more than doubled, and those of 1958 more than tripled by proper fertilization.

Yields of market coffee were increased by 870, 370, and 730 pounds per acre in 1956, 1957, and 1958, respectively, by the application of 150 pounds of nitrogen per acre yearly. Although there was no evidence of a response beyond this level during the very dry year of 1957, during the other 2 years there was an indicated response to the second increment of nitrogen fertilization, but it was not statistically significant. The trees receiving no nitrogen remained in extremely poor condition after the 1958 crop was harvested, as shown in figure 10.

Yields of market coffee were also increased greatly by the application of potash. When applied at the rate of 150 pounds per acre in 1956 and in 1958, yields were increased by 570 and 400 pounds per acre, respectively. In 1958, yields were increased by an additional 380 pounds when potash rates were increased from 150 to 300 pounds per acre. In 1957, yields were increased by 400 pounds per acre when 300 pounds of potash per acre were applied. The trees receiving no potash remained in very poor condition after the 1958 crop was harvested, as shown in figure 11.



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FIGURE 10.—Intensively managed coffee trees respond strongly to nitrogen fertilization. Trees on the left received 300 pounds of nitrogen per acre yearly in addition to an abundance of other nutrients and produced 1,890 pounds of market coffee per acre in 1958. Trees on the right were heavily fertilized with other nutrients but received no nitrogen; they yielded only 930 pounds of coffee per acre.

There was no significant response to phosphorus applications during any year. However, there was a strong indication of a response to the application of 150 pounds of phosphoric acid per acre during the first year.

From these data it appears reasonable to recommend the application of about 200 pounds of nitrogen, 80 pounds of phosphoric acid, and 300 pounds of potash (about a ton of 10-4-15 fertilizer) per acre yearly to mature, intensively managed coffee.

Owing to the high rainfall and extreme porosity of the coffee lands which favor leaching of nitrogen and potash, and to the strong phosphorous-fixing power of these soils, it seems best to make several fertilizer applications yearly. Although there is no experimental evidence, it seems logical to make three equal applications—one in October to help the trees recover from the effort of maturing the crop before the usually dry months of January through March set in; another in April to help produce vegetative growth for the following year's crop; and another in July to supply the nutrients required by the rapidly developing and maturing berries. The fertilizer should be evenly distributed under the trees starting about 6 inches from the trunk and extending to the tips of the branches.



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FIGURE 11.—Intensively managed high-yielding coffee trees respond strongly to fertilization with potash. Trees on the right received 300 pounds of potash per acre in addition to an abundance of all other nutrients. They produced about 60 percent more coffee 4 years after being transplanted than trees on the left, which were heavily fertilized with all other nutrients but received no potash. Also note difference in appearance of trees.

If a very large crop has set, it may be wise to apply an additional 60 pounds or so of nitrogen per acre (about 300 pounds of ammonium sulfate) in May or June to stimulate the production and retention of leaves needed to help manufacture the large quantities of carbohydrates that will be required later by the maturing berries, and to insure a good crop the following year.

Liming

Experiments in other countries indicate that coffee does well on most acid soils, provided an adequate supply of calcium is present. Analysis of the coffee soils of Puerto Rico show that they generally have an adequate supply of calcium if their pH is about 5.0 or above.

To determine the effect of liming on the productivity of intensively managed coffee, an experiment was conducted on Alonso clay soil having a pH of 4.8, and an exchange capacity of 16 m.e. per 100 grams with about 6 m.e. of exchangeable bases, mostly calcium. The coffee trees of the Bourbon variety were fertilized with 2,000 pounds of 10-5-10 fertilizer per acre yearly, and sprayed periodically to control insects and diseases. Results obtained with the first

large crop produced 3 years after the trees were transplanted are summarized below. All values are averages of 6 replicate plots of 12 trees each.

	<i>Yields of market coffee per acre (pounds)</i>
Upper 6 inches of soil limed to—	
pH 4.8-----	1, 930
pH 5.8-----	1, 890
pH 6.5-----	1, 715
pH 7.5-----	1, 850

To date, liming has had no apparent effect on coffee yields.

On the other hand, several experiments by the authors have shown that with heavy fertilization, soil acidity increases rapidly with a corresponding decrease in calcium content. In one experiment, a typical coffee soil—Catalina clay—was fertilized with a 10-5-10 fertilizer at the rate of about 2,000 pounds per acre yearly. At the end of 1 year the pH of the upper 6 inches of soil was decreased from 6.1 to 5.3 and the exchangeable bases (mostly calcium) had dropped from 14 to about 9 m.e. per 100 grams of soil. Similar results were obtained on other soils.

Thus, most coffee soils will soon require lime to neutralize the effect of the large quantities of acid residue from fertilizers. Proper liming should also help to increase the availability of the phosphorus fertilizer and favor the uptake of minor elements in desirable proportions.

Since lime moves very slowly into the soil, the opportunity for deep placement afforded at planting time should not be ignored. All soils having a pH of less than about 5.3 should be limed before the coffee seedlings are planted by working about 3 tons of limestone into the upper 6 inches or so of soil. If the land is not plowed, as is usually the case, 2 pounds of limestone should be mixed with the soil from each hole before the coffee is planted.

It is also recommended that 2 tons of limestone per acre be applied to heavily fertilized plantations about every 3 years. The limestone, if possible, should contain magnesium, must be finely ground, and be evenly distributed under the rows of coffee trees.

Minor Elements

Although symptoms of minor element deficiencies are rarely found in densely shaded, low-yielding plantations, intensively managed, high-yielding plantations in Puerto Rico frequently denote a severe deficiency of one or more minor elements. Deficiencies of zinc, magnesium, and Boron are widely prevalent.

The recommended fertilizer program should meet the needs of coffee for nitrogen, phosphorus, potassium, and sulfur (from the primary materials ammonium sulfate and superphosphate). Liming as recommended will provide the required calcium, and fungicidal sprays, the copper.

Thus, the probable deficiencies are limited to iron, manganese, zinc, boron, and magnesium, since the island's limestone usually has little dolomite.

A deficiency of iron is characterized by chlorosis of the young leaves, the veins remaining green during the early stages. Eventually the entire leaf may become yellow, but usually the size and shape are normal. Seedlings are particularly susceptible, but generally their growth rate is not reduced much. Symptoms of iron deficiency often appear during droughts and may disappear after the rains begin.

A deficiency of manganese is also evidenced by chlorosis of the leaves, but they are often lemon yellow in contrast with a pale yellow or whitish color of leaves deficient in iron.

Excessive quantities of manganese may be taken up by the coffee trees under some conditions, particularly on very acid soils, and uptake of iron reduced. Chlorosis and loss of leaves follow. A severe nutritional problem of this type was found by the authors on an intensively managed plantation on Catalina clay near Aguas Buenas. Trees treated with chelated iron turned dark green and 4 months later had grown almost twice as much as untreated ones. Liming may also be very helpful.

Symptoms of zinc deficiency are similar to those of iron, but in severe cases the young leaves are small, narrow, curled, brittle, and the internodes are short. Loss of leaves and dieback of the branches often follow. Typical symptoms of a severe zinc deficiency have been noted by the authors in three intensively managed plantations at widely separated locations in Puerto Rico and have been corrected by foliar applications of zinc sulfate as described later.

A deficiency of boron causes death of the growing tips, followed by the production of several secondary branches that give the twigs a broomlike appearance. Yields are very low. The leaves are often cupped and the young ones have chlorotic areas near the tips and edges. Symptoms are usually particularly noticeable at the start of the rainy season, at flowering or after liming. Severe symptoms of boron deficiency have been observed in two commercial plantations in Puerto Rico.

Symptoms of magnesium deficiency show up on the older leaves. Irregular chlorotic patches appear between the veins, progressing to necrotic areas near the tips. A green area often remains near the petiole. Severe symptoms of a magnesium deficiency were observed at two locations in Puerto Rico.

In addition to visual symptoms, leaf analysis may be used to diagnose a deficiency of minor elements. If levels of any element fall far below those indicated later on as being desirable, a deficiency may be suspected.

Deficiencies may be corrected in some instances by direct application of the element to the soil. Magnesium may be applied as dolomite in the limestone. Magnesium sulfate at about 200 pounds

per acre may be used when dolomite is not available. Applications must be repeated yearly. It takes from 12 to 18 months for symptoms of magnesium deficiency to disappear.

A deficiency of boron may be corrected by applying borax (11 percent boron) to the soil. About one-half ounce per tree twice yearly may be applied until the deficiency is corrected. Boron, particularly, should be used only under the direction of a competent technician, since it may be toxic to coffee if applied in excessive amounts.

Although other minor elements may also be applied directly to the soil as sulfates, they are frequently tied up by the soil and become unavailable to plants. Chelates—compounds bearing the desired minor element in a form in which it usually is not tied up in the soil—may be used to overcome this difficulty. However, there is little experimental information on their use under typical conditions in Puerto Rico.

Iron must always be applied as a chelate to the soil, since it is usually rapidly fixed in the soil and is not absorbed through the coffee leaves in appreciable quantities. About 15 grams may be applied to mature trees and a few grams to trees in the nursery.

Except for magnesium and iron, it is usually best and effects are obtained more rapidly by applying the deficient minor element in a foliar spray. Care should be taken to wet the leaves well on the undersides where absorption is fastest. A commercial sticker-spreader compound should be added to the solution. Frequency with which the spray is applied will depend on the severity of the deficiency; usually two applications a year during seasons of fast growth are enough.

Suggested quantities of material to use per 100 gallons of spray, enough to treat 1 acre of mature coffee, are as follows:

	<i>Pounds</i>
Manganese sulfate -----	3
Zinc sulfate -----	4
Borax -----	2
Calcium hydroxide ¹ -----	4
Sticker-spreader -----	(²)

¹ To neutralize any free sulfates.

² As recommended by manufacturer.

If mist or low-volume spray equipment is used, these materials should be mixed in about 15 gallons of water.

Since a widespread need for zinc is evident, it seems desirable to apply this nutrient to intensively managed plantations as a routine measure twice yearly, since it is cheap and harmless to coffee in normal amounts. As it is compatible with the ingredients of the recommended spray for insect and disease control, about 4 pounds of zinc sulfate and 2 pounds of calcium hydroxide (to prevent possible burning of young leaves) may be added to the mixture for an acre of coffee. It is also desirable to apply magnesium sulfate (epsom salts) to the soil under the coffee trees once a year at the rate of about 200 pounds per acre. Boron should also be applied in many cases, but

only under expert guidance. About $\frac{1}{2}$ ounce of borax per tree may be applied to the soil twice a year where deficiency symptoms are noted.

Foliar Analysis

Research on the use of leaf analysis as a guide to the fertilization of coffee is now underway in various countries. However, the information available is as yet very limited.

The fourth pair of leaves from the tip of primary laterals are often used and about 25 leaves are considered an adequate sample. Levels of the different nutrients in these leaves vary greatly with the season and other factors. Samples should be taken around flowering time, so that deficiencies may be corrected before the trees are subjected to the stress of maturing the crop. At flowering time, the following nutrient levels in the leaves appear to be adequate for the production of a heavy coffee crop.

Nitrogen	-----percent-----	2. 5-3. 0
Potassium	-----do-----	1. 7-2. 5
Phosphorus	-----do-----	. 1-. 15
Calcium	-----do-----	. 8-1. 4
Magnesium	-----do-----	. 4
Iron	-----p.p.m.-----	100
Manganese	-----do-----	150
Copper	-----do-----	10
Zinc	-----do-----	20
Boron	-----do-----	100

Levels much below these indicate a need for applications of the appropriate nutrient. More than about 400 p.p.m. of manganese or 200 p.p.m. of boron may represent toxic levels of these elements.

Manures and Plant Wastes

Coffee pulp is the only important source of plant waste in the coffee region, since it is not economical to transport filter-press cake from the sugar mills of the coast. Only negligible quantities of animal manure are available. An acre producing 1,500 pounds of market coffee will provide about $2\frac{1}{2}$ tons of pulp yearly.

Plant wastes contribute organic matter and nutrients to the soil. However, enormous quantities must be applied repeatedly in order to affect materially the organic-matter content of the soil. Also, rather large quantities must be applied to be effective as a fertilizer. For instance, about 1 ton of coffee pulp is required to supply the nutrients contained in 100 pounds of 10-3-14 fertilizer and about 1 ton of filter-press cake to supply the nutrients in 200 pounds of 9-11-3 fertilizer.

Manures or plant wastes should be used only if readily available and easy to apply. Farmers should compare, on a nutrient basis, the cost of applying manure with the purchase price and cost of applying commercial fertilizer. It will generally be found best to rely on a commercial fertilizer for the needed nutrients and on proper management practices for the maintenance of soil organic matter.

PRUNING

There are three main purposes for pruning coffee trees:

1. To provide for the growth of new bearing wood, as coffee usually bears only once on a given area. Since primary lateral branches bear most heavily, the pruning system should provide for their constant renewal.
2. To keep the trees low, since tall trees are costly and difficult to harvest and to spray and are more susceptible to hurricane damage.
3. To decrease variations in yield from one year to another by providing for the production of about the same amount of bearing wood each year. Improperly pruned trees evidence strong biennial fluctuations in yield and are subject to dieback in the year they bear too heavily.

Two essential requirements of a pruning system in Puerto Rico are that it not be time consuming, since labor is relatively expensive, and be simple so that it can be practiced by unskilled labor.

The first step in pruning is the formation of the basic system of branches. Three general systems are used—the single-stem, the Costa Rica, and the multiple-stem systems.

In the single-stem system the trees are limited to one vertical branch. To keep the trees low they are usually topped at a height of not more than 8 feet. When the bearing area gets too far from the main stem, the primary laterals are cut back to a strong secondary and the process repeated when they also become too long. Although by this system the trees are kept low and sturdy, a great deal of careful work is required and for this reason alone the system is not practical in Puerto Rico.

In the Costa Rica system the trees are capped when they are knee high and two verticals are allowed to develop from the leaf axils just below the cut. These verticals in turn are capped when they are waist high and two others are allowed to develop from each. In some cases these four verticals are again capped when they are shoulder high and two verticals allowed to develop from each. Thus, the basic structure of the tree resembles a candelabra. The authors have found this system undesirable, since the verticals split away easily when the branches are bent over in picking or during high winds.

In the multiple-stem system the trees are encouraged to produce several verticals and develop into a bush, which is very easy to prune. This basic structure appears best in Puerto Rico, and is recommended, particularly since experiments have shown that yields are usually higher on multiple-stemmed trees than on those limited to one stem.

It is of great importance that there be a wide difference in the development of the verticals. If several come into full production at the same time, there is danger of overbearing and dieback, and low yields the following year. To avoid this danger, only one or two new shoots should be allowed to develop each year until the trees have four or five verticals of different ages which can be pruned in rotation as described later.

Coffee naturally tends to produce several main vertical branches, often after the trees bear their first heavy crop. If necessary, the production of verticals may be stimulated by bending the tree over and staking it to the ground, or by notching the stem at a height of about 3 feet, or by cutting off the lower primary laterals on one side of the tree.

The early production of verticals reduces the danger of precocious overbearing, since some of the trees' energies are diverted to their growth. Furthermore, should dieback occur on the main stem, it can be cut off after the crop is harvested and the following crops be produced on the new verticals with little loss in production. A good system of assuring the early production of verticals is to plant the tree at a slight angle, thus reducing the dominance of the apical bud and encouraging the production of shoots, only one or two of which should be allowed to develop each year.

The following system of pruning is recommended for the multiple-stemmed coffee bushes. The main stem bears a crop or two, but is cut off once the oldest vertical starts bearing. After about the third crop, when the tree has two or three verticals, the oldest or poorest looking one is cut back to a 4-inch stump which soon produces several shoots, only one of which is allowed to develop. These shoots may grow from 4 to 5 feet in a year. This procedure is repeated every year after harvesting, the oldest or poorest vertical always being removed and a new one allowed to grow in its place. With this system the oldest vertical is never more than 3 or 4 years old and at any given time a tree has one vertical in full production, one bearing lightly, and the youngest in an early stage of development. The verticals should arise from the main stem at a point no higher than about 4 feet above the ground, should be well spaced, and vigorous. Trees pruned in accordance with this system are shown in figure 12.

This method meets all the requirements of a good pruning system. Bearing wood is constantly replaced, the trees are kept low, and a rather uniform quantity of bearing wood is maintained that reduces variations in yield from one year to another and decreases the danger of overbearing. Finally, the system is simple and cheap to carry out.

This method may be modified considerably to suit different conditions and the individual characteristics of the trees. It is unwise to attempt to force all trees into a rigid pattern of development. The only essential is that the principle of maintaining several vertical branches of different ages on each tree be adhered to. In close-growing rows it may be necessary eventually to eliminate every other tree or to restrict it to one vertical to avoid overcrowding.

Pruning should be carried out soon after harvesting and all broken or diseased branches cut off. Excess suckers should be removed before they are more than a few inches long and constitute a drain on the trees. It is therefore necessary to go over the entire plantation several times a year to carry out this simple, yet essential operation.



FIGURE 12.—Four-year-old coffee trees pruned by multiple-stem system. The main stem was removed after bearing the first crop. By this time the vertical stems shown in the figure were well developed. A, Verticals starting too close to the ground and rather closely spaced; there should be a greater difference in age and development between the verticals, so that not more than two will bear heavily any one year; B, verticals trimmed as recommended, starting higher up and more widely spaced along the main stem.

PESTS AND THEIR CONTROL

It has been shown conclusively that a close relationship exists between leaf area and coffee yields. Continuously high yields of coffee can be obtained only if a large, healthy leaf surface is maintained. Since the most damaging pests of coffee in Puerto Rico are precisely those that cause defoliation, importance of pest control can hardly be overemphasized.

Diseases

Three species of fungi cause defoliation of coffee trees in Puerto Rico. *Omphalia flavida* causes eyelike leaf lesions, commonly called "ojo de gallo" (fig. 13, B). This fungus produces a toxic substance that causes the leaves to drop. *Cerospora coffeicola*, called "mancha de hierro," causes small, round leaf spots (fig. 13, A) and mummification of berries. This fungus is often responsible for severe defoliation of young coffee trees, particularly of seedlings, and seems to be a more serious pest of coffee growing in strong sunlight than of that grown in dense shade probably because of greater dew formation on the former. *Pellicularia koleroga* (fig. 13, C), commonly called "moho de hilacha," may cause considerable defoliation of coffee trees growing in humid, heavily shaded areas. The clearly visible mycelia of this fungus and the dry coffee leaves that remain dangling from them easily identify this disease. This fungus and



A-PN 674. B-PN 675. C-PN 676. D-PN 677

FIGURE 13.—Pests that defoliate coffee in Puerto Rico: A, “Mancha de hierro” (*Cercospora coffeicola*). Initially small, almost circular lesions may cause necrosis of surrounding tissue and loss of leaves. B, “Ojo de gallo” (*Omphalia flava*). “Eye-like” lesions with necrosis of surrounding tissues followed by leaf drop. C, “Moho de hilacha” (*Pellicularia koleroga*). Dry leaves hang down from twigs by clearly visible mycelia of the fungus. D, Leaf miner (*Leucoptera coffeella*). Irregular lesions are produced by the larvae burrowing in the leaf tissues which soon dry out and fall away. Lesions reduce photosynthetic area and cause leaf drop.

omphalia rarely attack coffee growing in strong sunlight in Puerto Rico. All three fungi are controlled with the copper in the recommended spray mixture. Fermate at the rate of 1 pound per 100 gallons of water has also been found effective.

A black, sooty mold often covers the leaves of coffee trees affected by scale insects on whose excretions it thrives. Damage to the coffee by this nonparasitic fungus is limited to its shading effect on the leaves which may reduce photosynthesis. This fungus soon disappears when the scale insects are controlled.

Another species of fungus, *Colletotrichum gloeosporioides*, invades weakened tissues of coffee and is frequently associated with dieback, a condition in which the young branches become blackened and die. *Colletotrichum* is probably only a secondary invader, since spraying with fungicides controls this fungus but does not generally reduce the incidence of dieback. Dieback may follow a very heavy crop or unfavorable weather. *Colletotrichum* also causes lesions on the berries, some of which are eventually mummified. It may be controlled by maintaining the plantations in a vigorous condition and by spraying with a solution containing a copper compound or Fermate.

Young coffee seedlings are often attacked by fungi of the genera *Fusarium* or *Pellicularia*. The tender stems become dark and constricted near the ground and the plants soon die. The disease spreads rapidly in close growing seedbeds. It may be controlled by treating the seedbeds with a spray containing 2 pounds of a copper compound (about 1 pound of metallic copper) per 100 gallons of water. Fermate at the rate of 3 pounds and Arasan at the rate of 2 pounds per 100 gallons of water are also effective. At least the upper inch of soil should be well wetted with the solution. The recommended spray treatment may help to control this disease by virtue of the copper it contains. Proper drainage and removal of excess shade should also be helpful.

Fusarium bulbigenum causes a root rot and crown disease of coffee that kills some trees throughout almost all coffee plantations in Puerto Rico. The symptoms are wilting, yellowing of the leaves, and defoliation, usually followed by death. Some trees eventually recover but do not bear for about 2 years. All species of coffee are apparently susceptible to this disease, and the organism is found in almost all soils apparently attacking trees whenever their resistance becomes low. Although proper management of the plantations may help, there is no known practical method of controlling root rot. Apparently farmers must resign themselves to losing some of their trees until effective control measures or resistant varieties are developed.

Observations indicate that the incidence of this disease is greatest with young trees bearing their first crops. From 5 to 10 percent of the trees under intensive management were affected by root rot during the first 2 or 3 years, but less than 1 percent during the fourth and fifth years. Although a wide range of fertilizer and lime variables

were included in these experiments, they had no apparent effect on the incidence of root rot.

Fortunately, the dreaded leaf rust of the East (*Hemileia vastatrix*) is still unknown in the Western Hemisphere. *Robusta* coffee is resistant to this fungus and workers in the U.S. Department of Agriculture have selected varieties and strains of *Coffea arabica* that also appear to be resistant to this fungus. These species offer the best hope for controlling this disease, although a degree of control can be attained by the periodic application of copper sprays.

Insects

The leaf miner *Leucoptera coffeella* (fig. 13, D) is the most serious insect pest of coffee in Puerto Rico and is largely responsible for the defoliated condition of most plantations. Farmers frequently overlook the harm done by this insect, which apparently is more prevalent during dry weather, since the affected leaves soon drop off and the flush of new growth obscures the damage. However, coffee cannot replace fallen leaves and the long, bare branches testify to the depredations of this insect (fig. 1). The leaves of *Coffea stenophylla*, a little known species of coffee, are apparently immune to attacks by this insect. The recommended spray treatment affords excellent protection against the leaf miner. A spray containing BHC (benzine hexachloride) has also been found to be effective against this insect in Brazil, as has Bayer L 13/59 or Dipterex in Costa Rica.

An ant *Myrmelachista ambigua ramulorum* Wheeler eats out tunnels in the stems and branches of coffee and shade trees, occasionally causing the branches to break off during windy weather. These ants are often associated with scale insects and may cause considerable fruit drop. Since the ants live in the shade trees from hence they attack the coffee, they do not constitute a problem in sun plantings. They may be controlled by spraying the coffee trees with the recommended spray mixture.

The green scale (*Coccus viridis* (Green)) and the hemispherical scale (*Saissetia hemisphaerica* (Targione)) can seriously harm coffee trees, particularly young ones, during dry weather. These insects spread rapidly in seedbeds and can cause serious damage if not controlled immediately. The seedlings become yellowish, lose many of their leaves, and may even die. Scale insects are controlled with the recommended spray treatment, which also kills the ants attending the scales, thus having a double-barreled effect. If the attack is serious, the spray, without the copper, should be repeated at 5- to 8-day intervals until all scales are dead, as evidenced by their dry state when scrapped off the trees. Two applications are usually sufficient. Malathion (4 pounds of the 25-percent wettable powder per 100 gallons of water) or Volck (1 part flowable oil in 50 of water by volume) may also be used to control scale insects. Volck should be applied with care, for it may burn the leaves of seedlings under some conditions.

In the field, scale insects are usually kept under control by a parasitic fungus that thrives during wet weather. The naked eye can easily see this white fungus among the affected scales. When scales are a serious pest, it is wise to use fungicidal copper sprays judiciously in order to give this fungus an opportunity to spread and control the scales.

Many other insects attack coffee in Puerto Rico, but generally do not cause important damage. The beetles *Lachnopus coffeae* Marshall and *Phyllophaga* spp. eat the tender coffee leaves, while their grubs attack the roots. The grubs are controlled by spraying the soil before planting with an aqueous solution of aldrin at the rate of 2 pounds of the technical material (1 gallon of emulsifiable concentrate containing 2 pounds of aldrin in 50 gallons of water) per acre. If necessary, the soil under the coffee trees may be sprayed once a year with this solution to control grubs. These beetles are most abundant in spring. Aphids and mealybugs also occasionally attack coffee and may be controlled with the recommended pesticide spray.

Rats may gnaw and break off the young branches of coffee trees. They also chew the berries and knock them off the trees. Various commercial compounds may be used as baits to kill these pests.

Snails can also be harmful to young seedlings, gnawing the young stems and eating the leaves. Various commercial poison baits containing calcium arsenate are very effective in controlling them and should be used at the first sign of damage.

Workers at the Agricultural Experiment Station of the University of Puerto Rico have found large nematode populations on the roots of poorly developed coffee trees at various locations on the island.

Pest Control

It is absolutely essential that diseases and insect pests be controlled if high yields of coffee are to be produced. The high income that can be produced by intensively managed plantations warrants the use of even complex control measures if found to be necessary. Although limited areas may have no serious pest problems, farmers will generally find that a thorough program of pest control is well warranted. It should be emphasized that pests are less of a problem if they are kept under control from the time the plantation is started.

The damage done to coffee plantations by the various pests can be greatly reduced through proper hygiene and management. All infected materials should be destroyed periodically and every effort be made to keep the trees in as vigorous a condition as possible through heavy fertilization and proper pruning.

Fortunately, an effective spray has been developed and tested at the Agricultural Experiment Station of the University of Puerto Rico. In a carefully controlled experiment, trees sprayed with this mixture are almost free of pests, show far superior development, and yielded more than twice as many coffee berries as the untreated trees.

Through the use of this spray the authors' experimental plantings and several commercial ones have also been kept virtually free of insect and disease pests attacking the leaves, although neighboring areas were severely affected.

This spray, which is recommended for the treatment of pests of coffee trees, contains the following materials, one or the other of which controls all the major diseases and insect pests of coffee thus far controlled.

Recommended pesticide spray

Parathion, 15-percent wettable powder.....	1½ pounds.
Dieldrin, emulsifiable concentrate containing 1-½ pounds per gallon.....	2 quarts.
Copper-A compound.....	2 pounds.
Sticker-spreader.....	Follow instructions of manufacturer.

For use with a high-volume or knapsack sprayer, dilute the above ingredients with 100 gallons of water and apply at the rate of from 50 to 100 gallons per acre depending on the size of the trees. For a low-volume or mist sprayer, dilute with 15 gallons of water and apply from 5 to 15 gallons per acre.

For a 5-gallon knapsack tank, use about 11¼ ounces of the parathion, 95 cc. of the dieldrin, 2 ounces of copper-A compound, and 1 tablespoonful of sticker-spreader in 5 gallons of water.

Spraying every 3 months afforded good protection to small plantings surrounded by heavily infected plantations. With large plantings it may be necessary to spray only twice a year as reinfestation will be slower.

Since the cost of spraying is small in relation to the possible increase in yields, it is recommended that the complete spray be used in most cases. When only insect damage is noted, however, the copper compound should be omitted, since it kills fungi which prey on the scales and help to keep these serious pests under control.

The excessive use of copper sprays may cause yellowish spots to appear on the coffee leaves. Some of the insecticides may also be harmful under certain conditions. However, no harmful symptoms have been observed in plantings sprayed as recommended.

The use of knapsack sprayers is practical with young coffee trees up to about 2 years of age, but motor-driven equipment is required to attain efficient operation and proper coverage of older coffee trees. High-volume spray equipment may be used, but low-volume or mist sprays are generally more practical.

Mist sprays may be applied with simple equipment such as that shown in figure 14. Only about 15 gallons of spray are required per acre, and from 4 to 8 acres can be sprayed per man-day. Excellent coverage can be attained with these lightweight sprayers operated by a small gasoline motor and the materials are kept well mixed at all times. The manufacturers instructions covering operation and care of the equipment must be carefully followed.



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FIGURE 14.—A low-volume mist sprayer is very useful in applying insecticides and fungicides.

A comparable pesticide mixture can also be applied in a dust with a motor-driven or single hand-operated bellows type of knapsack equipment.

Following are six points to remember in spraying.

1. *Spray as soon as lesions appear*, for pests can propagate rapidly if not controlled promptly. Particular care should be taken in the seedbed, since seedlings are especially susceptible to attacks by pests. Plantations should be sprayed at set intervals, say every 3 months, for at least the first few years.

2. *Do not spray during wet weather*, as rains will wash off the poison. If it rains soon after spraying, the treatment may have to be repeated within a short time.

3. *Cover all the foliage with spray*, taking care to wet the underside of the leaves by turning up the nozzle.

4. *Mix the ingredients not more than a few hours before spraying*, for they lose their effectiveness if in contact too long.

5. *Keep the spray solution thoroughly mixed*, both before starting to spray and after any interruptions. Be sure the agitator in the sprayer works properly.

6. *Use this spray with caution, as parathion and dieldrin are highly poisonous.*

Follow all directions and heed all cautions on the labels. Proper masks, goggles, and gloves should be used while mixing and applying the spray. The mixture should never come in contact with the skin. Do not spray against the wind. After spraying, bathe thoroughly with abundant soap and water. The last spray should be applied not later than August to insure against having toxic residues on the berries at harvesttime.

HARVESTING AND PROCESSING

In Puerto Rico it is necessary to go over the plantations four or five times during the harvest season, as the berries ripen irregularly and it is best to pick only fully ripe ones. However, all yellowish-green berries may be picked, especially during the last picking to reduce costs.

The equipment for picking coffee is usually limited to a small basket attached to the picker's waist and burlap bags for transporting the berries to the processing plant. Since it is not possible to use ladders on the steep coffee lands, tall-growing trees must be bent over. Various types of hooks may be used for this purpose in order to keep both hands free for picking. A laborer can pick from 200 to 300 pounds of berries daily in a properly managed, high-yielding plantation. Generally 100 pounds of berries yields about 22 pounds of parchment coffee, or approximately 18 pounds of market coffee.

A brief description of the coffee berry and of some terms will make the discussion that follows easier to understand. The "green" beans or dry market coffee are covered by a thin membrane, the "silverskin." Surrounding this is a tough cover, the "parchment." Two beans, each in a parchment cover and surrounded by a layer of mucilage and by the pulp and outer skin, constitute a coffee berry.

Coffee is processed by two methods—dry and wet. In the former the whole coffee berries, as harvested, are dried and then milled to yield the green market coffee. This method results in coffee of poor quality. In the wet method the pulp and skin are removed, the mucilage is fermented off, and the beans are washed and then dried, after which the parchment and silverskin are removed. When properly practiced, this method results in a good quality of mild coffee that brings premium prices. Only the wet method of processing is recommended, at least for Puerto Rico, and will be discussed here.

Coffee must be completely processed as soon as possible, preferably within 24 hours of picking, since metabolic processes continue until the beans are dry and may cause considerable loss in weight and especially in quality.

In the processing of coffee the first step is the removal of the skin and pulp. This should be done as soon as possible, as the pulp ferments rapidly generating heat which causes the beans to sour. A few such beans will affect the quality of the processed coffee. The machine for removing the skin and pulp is called a pulper and usually consists of a rough surface revolving at a short distance from a fixed plate. As the berries pass between these surfaces the skin and pulp are torn off and ejected from one side, while the beans pass out into a container or directly into the fermenting vats. Since pulpers depend on the slippery mucilage under the skin of the beans to prevent them from breaking, green or fermented berries that have little mucilage may be damaged in pulping. Good beans may also be damaged if stuck in the pulper behind one that is not slippery. The pulper should be maintained in proper adjustment

and operating condition, for a poorly adjusted one can damage many beans and lower the quality of the coffee.

The next step is the removal of the mucilage, which is slimy and insoluble in water. If the mucilage is not removed, it interferes with drying and even after the beans have dried out, will continue to take up moisture from the air and keep them sticky.

There are three methods of removing the mucilage. In the most common one the mucilage is allowed to ferment while the beans are in large vats. The vats should contain little water, so that optimum temperature of about 90° F. is rapidly attained and fermentation expedited. This process must be completed as soon as possible, since the beans lose considerable weight if allowed to ferment too long. If done properly, from 12 to 24 hours should be sufficient. The addition of commercially available enzymes hastens fermentation, so that it can be completed in a few hours. Enzymes should always be used in accordance with the manufacturer's instructions. Fermentation is complete when beans rinsed in clean water are no longer slippery. The beans should then be removed immediately to prevent loss in weight and quality.

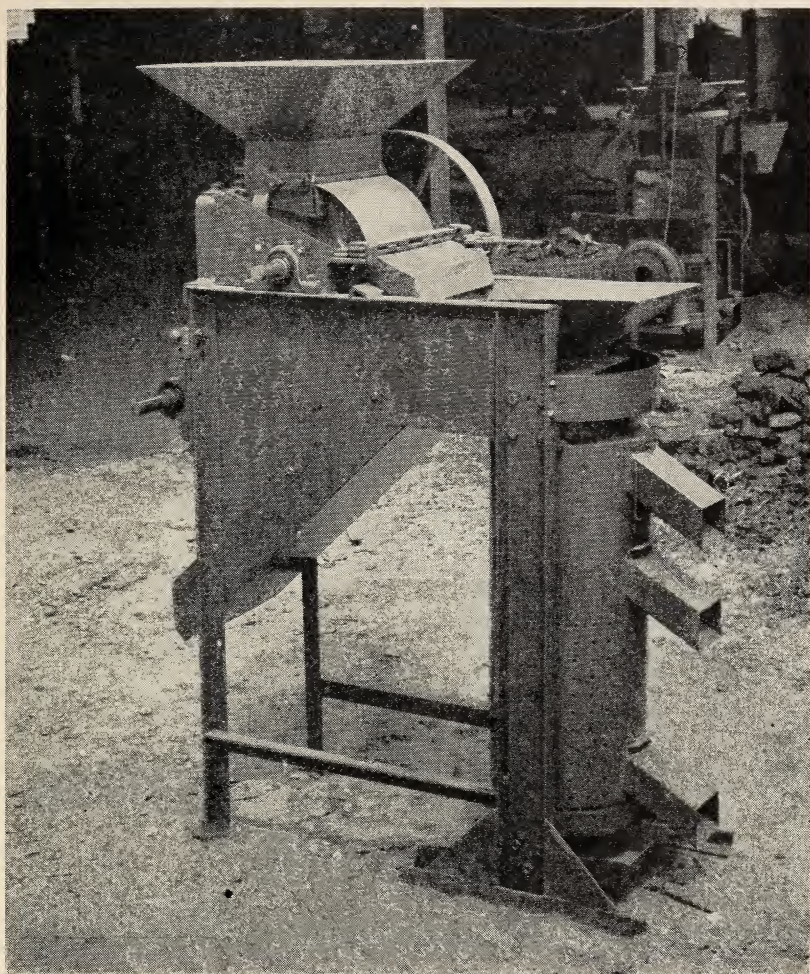
In another method of removing the mucilage, beans are treated with a dilute solution of sodium or potassium hydroxide which breaks down the mucilage in only a few seconds. Machines have been devised to treat the coffee beans with these alkaline solutions and wash off the broken-down mucilage in one continuous process. Treatment with alkali in this manner does not affect the quality of the coffee and the beans lose less weight than with the common fermentation method. One disadvantage, however, is that the alkali is corrosive to human skin.

With both these methods the beans must be washed well in clean water before being dried.

In the third method the mucilage is removed mechanically. In one machine, which is rather large and heavy, the beans are moved back and forth rapidly in square compartments and the mucilage is removed mostly by the beans rubbing against each other.

In another type of machine the beans are beaten about in a cylinder in a manner similar to a washing machine. The water and mucilage come out one side and the beans from another. Machines of this type are recommended particularly for small farms, since they are small and relatively cheap. They are also simple to operate and care for, and the process of demucilaging is continuous and fast.

Combined pulpers and mechanical washers are available at reasonable prices. One type (fig. 15) weighing only about 400 pounds can process berries equivalent to several hundred pounds of market coffee per hour and occupies only about 8 square feet of floorspace. Cost of this equipment, plus a small drier, building, and other facilities, total about \$4,000. These facilities can handle the output of about 50 acres of high-yielding coffee. Such a plant permits the continuous processing of coffee and, if properly operated, insures a high-quality product.



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FIGURE 15.—A simple, low-cost machine for removing pulp and mucilage from the coffee bean in one operation. This machine is good for the small farmer. Use of a small drier would complete the equipment required to process coffee effectively.

After the mucilage is removed and the beans are washed, they should be dried as soon as possible to avoid moldiness and fermentation. In Puerto Rico, beans are often dried in the sun on large cement yards called *glacis*. The beans are spread out in a thin layer and moved about periodically with rakes to insure uniform drying (fig. 2). The beans are raked into piles and covered with tarpaulins during the night or when it rains. Large, movable trays that can be pushed under a roof are also used. From 4 to 7 days are required to dry the beans in sunny weather. This method has the disadvantage of being dependent on the weather.

Generally it is best to dry the coffee for a day or two in the sun and then complete the process in artificial dryers. There are various types of dryers, but the revolving drum is the one most widely used. The most effective drying temperature is probably between 130° and 140° F. The beans lose most of their aroma and are ruined if heated above 150°. All heaters should be equipped with thermostats to control the temperature.

The dryness of the beans should be ascertained periodically with a moisture meter or by removing the parchment from some of the beans and biting them. If not properly dried they will be somewhat soft, but if well dried they will break if bitten hard enough. As the beans begin to dry they become dark in color but turn green when completely dry.

After being washed, the beans have a moisture content of about 50 percent, whereas beans for market should only have about a 12-percent content. Beans will spoil if stored with a moisture content of more than about 14 percent. On the other hand, the loss in weight by overdrying penalizes the farmers.

At this state of processing, the beans are called parchment coffee and it is in this form that they are sold by farmers. Cooperatives or large millers later remove the parchment and silverskin and sell the beans as so-called green, or market, coffee.

Coffee for the U.S. market is graded by the number of imperfections (beans that are sour, black, broken) contained in 1 pound of green coffee and by cup tests. Coffee for some of the European markets is also graded by the size and appearance of the bean.

Several factors affect bean size. The Bourbon variety produces smaller beans than common *arabica*. Older trees tend to produce larger beans, and primary laterals larger beans than secondaries. Large beans are generally produced at higher elevations and when there is abundant moisture while the berries are developing. When all factors are unfavorable, bean size may be reduced by as much as a third.

GENERAL DISCUSSION

The recommended practices for intensive coffee production in Puerto Rico may be summarized briefly as follows:

Use superior, high-yielding varieties of coffee planted close together in contour rows.

Grow them in strong sunlight.

Fertilize heavily several times a year with a fertilizer high in nitrogen and potash and apply lime and minor elements when required.

Spray the trees periodically to control major diseases and insects.

Encourage the trees to produce several vertical stems of different ages and prune in rotation.

Maintain proper erosion control.

Process the coffee carefully with proper, modern equipment.

Only farmers disposed to carry out carefully *all* these essential practices should attempt intensive coffee culture. Omitting just one practice can jeopardize the entire effort. Improper fertilization, for example, can ruin an otherwise well-cared-for plantation (figs. 10, 11), as can a lack of proper insect and disease control or failure to prune and manage the plantation properly. Certainly, poor processing can ruin the best crop.

It should always be kept in mind that whereas trees yielding little under dense shade can stand considerable mismanagement, intensively managed plantations producing at close to maximum capacity may suffer severe damage if neglected. The need for constant care is the price of high yields.

The recommendations in this bulletin and the suggested general schedule of operations shown in table 6 have been prepared for

TABLE 6.—*General schedule of operations for intensively managed coffee plantations in full production under typical conditions in the coffee region of Puerto Rico*

Month	Spray ¹	Ferti- lize	Prune	Weed control	Har- vest	Miscellaneous
January			Prune and desucker.	X		Repair ma- chinery, farm roads, fences; apply lime.
February	X	(²)				
March						
April		X		X		
May	X		Desucker			
June		(³)				
July		X	Desucker	X		
August	X					
September			Desucker	X		
October		X			X	
November					X	
December					X	

¹ Spray also at any time damage is observed; add zinc to May and August applications.

² Apply magnesium and boron to soil; apply lime.

³ Apply nitrogen if crop is very large; repeat boron applications if needed.

average conditions in the coffee region in Puerto Rico and may be modified considerably to suit particular situations. For example, spraying twice a year may be sufficient in some areas, while pruning may be considerably modified to suit individual trees. However, modifications in the recommended practices should be made with caution and should be based on careful, repeated observations.

Overbearing

Intensively managed, high-yielding coffee plantations are susceptible to a condition that may be termed "overbearing," but is more commonly known as dieback in reference to the symptoms evidenced by the trees. Occasionally so large a crop is set that the trees can-

not meet the demand for carbohydrates, and of mineral nutrients if they are not applied in adequate amounts, made by the rapidly developing and maturing berries. The leaves on the bearing branches turn yellow first and then fall off, and sometimes many of the berries do not fill out. Later, these branches may dieback from the tips, becoming dry and blackened. *Colletotrichum gloeosporioides* is found on such branches probably as a secondary invader of the weakened tissues. The upper part of the tree, which is not bearing, is generally not affected, while young, lightly bearing, vertical shoots rarely evidence damage even when the main stem dies back severely. Since affected trees cannot produce much vegetative growth, the following crop is small. Figure 16 shows a plantation suffering from dieback.



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FIGURE 16.—Proper management greatly reduces dieback. Unfertilized, improperly pruned trees on the left were severely damaged, while heavily fertilized, properly pruned trees on the right suffered little. Note natural grass cover protecting the soil between the rows of coffee.

Since dieback rarely occurs in low-yielding plantations under dense shade, farmers in Puerto Rico have little knowledge of it. It is therefore felt that this problem merits detailed discussion here.

Certain conditions favor dieback. The Bourbon variety appears to be particularly susceptible. It is especially prevalent with coffee trees bearing their first heavy crop at 2 to 3 years of age and is much rarer among older trees that have had time to adjust to their

environment. If the previous crop was light, and, as a result, an abundance of bearing wood was produced, there is danger of dieback during the following year. A dry winter followed by light spring rains that stimulate flowering and allow heavy fruit set also favors this condition. A drought from May to July, when the crop is maturing and making maximum demands on the trees, increases dieback. When all these conditions occur in one year, damage to plantations can be serious.

One way of reducing dieback is through the use of dense shade, but since yields are greatly reduced this method cannot be recommended. Another way is to use a later maturing variety of coffee such as *Columnaris*, that carries an abundance of leaves in proportion to berries, but again yields are sacrificed.

Through proper fertilization and pruning much can be done to reduce dieback and maintain uniformly high yields, although considerable variation will always occur from year to year. The heavy recommended fertilization with nitrogen and potash reduces dieback. Properly fertilized trees produced a much heavier crop, yet suffered less from dieback than did inadequately fertilized ones (figs. 10, 11). An application of nitrogen in May or June in years when a heavy crop is set may also help. Nitrogen stimulates the production of new growth, which can later supply the maturing berries with the required carbohydrates and provide bearing wood on which the following crop can be borne, thus preventing a large decrease in yields during the next year.

The recommended pruning system helps to prevent dieback by maintaining rather even production. If properly carried out, about the same amount of bearing wood is available each year. Even if the older stems dieback, they can be cut off after harvest and subsequent crops can be borne on the younger verticals with little loss in production. It is of the utmost importance that the verticals be of widely different ages, for if all bear heavily in any one year damage to the trees may be as severe as with single-stemmed trees. Figure 16 shows how the recommended system of pruning combined with proper fertilization reduces damage caused by overbearing.

The danger of dieback may be reduced further by using the size of the crop and the amount of vegetative growth as a general guide for pruning and fertilization. If the previous crop was small and an abundance of bearing wood was produced as a result of favorable climatic conditions, there is danger of overbearing and dieback during the current year. Rather heavy pruning is called for to reduce the amount of bearing wood and thus the size of the expected crop. Also, heavy fertilization is needed to build up the trees' reserves for maturing the expected heavy crop and for producing vegetative growth on which to bear a good crop the following year.

If the previous crop was large and little bearing wood for the current year was produced, pruning should be light so as not to reduce the expected crop. Fertilization should be moderate, for if

too much fertilizer is used a great deal of new bearing wood may be produced which may result in overbearing and dieback the next year.

In summary: If the last crop was small and the vegetative growth heavy, the trees should be pruned heavily and fertilized heavily. If the last crop was heavy and the vegetative growth light, the trees should be pruned lightly and fertilized moderately. If both the previous crop and the vegetative development were moderate, pruning and fertilization should also be moderate.

Rehabilitation After a Hurricane

Repeated observations were made on plantations directly in the path of a 100 m.p.h. hurricane that hit Puerto Rico in 1956. The shade trees suffered heavily, some were completely uprooted, and most of the branches were broken off. Debris from the shade trees fell on the coffee trees, causing considerable damage.

The leaves were blown off the coffee trees, some branches were broken, and most of the coffee berries were lost. Although all the trees were strongly shaken and bent over and many were partially uprooted, few died. Also of great importance were the after effects. When coffee trees are suddenly exposed to full sunlight, they receive a great shock. Furthermore, weeds grow tremendously after removal of the shade, competing strongly with the weakened coffee trees. Removal of the debris of the shade trees is costly and must be done soon after the hurricane when labor is scarce. Replacement of the trees naturally takes a long time. Added to the need for rapid, costly operations is the farmers' natural depression and reluctance to invest money in low-yielding, marginal plantations.

Many of these problems do not exist or are ameliorated in plantations managed as recommended in this bulletin. Since there are few, if any shade trees, efforts can be concentrated on the coffee trees themselves with the knowledge that high yields may be obtained again soon. The trees are already adapted to strong sunlight and are in a vigorous condition, while weed growth has been controlled as a result of proper management and should not be more of a problem than before the hurricane.

Although there is little reliable information on the best method of rehabilitating coffee plantations damaged by a hurricane, general scientific principles and careful observations permit some tentative recommendations. All broken or twisted branches should be cut off, and completely uprooted trees should be removed. Those that have been bent over should not be disturbed, since they will soon produce shoots that will develop into a new tree. About 800 pounds per acre of a 10-10-10 fertilizer should be applied soon after the hurricane. The trees should be sprayed for insect and disease control as soon as they start putting out new leaves and the treatment repeated as required. Excess shoots should be removed periodically.

A severely damaged plantation treated in this manner had healthy new suckers 5 feet tall only 10 months after the hurricane and an

excellent crop was produced in 1958. Thus, only the crop on the trees when the hurricane hit and that of the following year were a total loss. Hurricane insurance can cover a considerable part of the loss of the crop and of the cost of rehabilitating the plantations.

Costs and Profits

Some discussion of the cost of managing a plantation in accordance with recommendations and of the profits that can be expected may be of interest. This, of course, applies only to Puerto Rico.

A yield of 1,500 pounds of market coffee per acre appears reasonable under favorable conditions in the coffee region, provided all the recommended practices are properly carried out. Lower yields may be obtained when proper care is lacking or under less favorable conditions such as those found near the periphery of the coffee region. Some of these areas are too dry, others are rocky or have shallow soils, or are too low in elevations.

Although costs will naturally vary under different conditions, reasonable figures have been obtained from a commercial planting where all recommended practices were followed. Approximate costs of establishing and bringing an acre of intensively managed coffee into commercial production over a 3-year period are shown below. Also shown are the costs of harvesting and processing the first crop. Wages of 40 cents per hour rather than the current 30 cents are assumed, as is a price of 50 cents per pound of coffee.

Materials and other:

Fertilizers (2 tons)-----	\$120
Lime (2 tons)-----	10
Insecticides and fungicides-----	30
Herbicides-----	50
Seedlings (1,300 @ about 3 cents, cost of producing each)----	40
Crop, plantation and labor insurance, taxes, farm upkeep-----	60
Total cost for materials and other-----	310

Labor:

Land preparation and planting (240 man-hours)-----	96
Application of fertilizer and lime (60 man-hours)-----	24
Spraying (30 man-hours)-----	12
Weed control (220 man-hours)-----	88
Miscellaneous (15 man-hours)-----	6
Total labor (565 man-hours)-----	226

Total cost of establishing and bringing plantation into production--	536
Cost of harvesting and processing 1,500 pounds of market coffee produced at end of third year.-----	180
Total cost of establishment, harvesting, and processing first crop--	716
Gross income from 1,500 pounds of market coffee selling at 50 cents-----	750
Net income after return of all investment except cost of land-----	34

A total investment of about \$536 over a 3-year period is called for. Profit from the first crop should return the entire investment plus a small net profit. In addition, a considerable profit may be realized from bananas or plantains intercropped with the coffee for 2 years.

The approximate costs of production and income that may be expected yearly for an acre of intensively managed coffee plantings in full production after the third year are as follows:

Materials and other:

Fertilizers (1 ton).....	\$60
Lime, insecticides, fungicides.....	20
Herbicides.....	20
Other supplies.....	6
Crop, plantation, and labor insurance.....	55
Farm upkeep and taxes.....	9
Marketing.....	20

Total cost for materials and other.....	190
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Labor:

Applying fertilizer, lime and spraying (50 man-hours).....	20
Pruning (40 man-hours).....	16
Cultivation (30 man-hours).....	12
Harvesting and processing (450 man-hours).....	180
Miscellaneous (10 man-hours).....	4

Total labor (580 man-hours).....	232
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Total costs of production.....	422
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Gross income (1,500 pounds of market coffee selling at 50 cents).....	750
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Net income.....	328
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Net annual income should be about \$328 per acre. Even with coffee at 40 cents a pound and labor at 50 cents an hour, net annual profits would be about \$126 per acre, certainly an excellent return on a total investment of about \$700 including cost of land and facilities and bringing the plantation into production.

An average family could easily care for 4 acres of intensively managed coffee from which it could derive an income of about \$2,200 yearly after deducting costs of materials and other charges.

These data show how important it is to reduce harvesting costs which account for over 50 percent of the total production expenses. In this connection, a study was made by the authors on efficiency of picking. The plots of the fertilizer experiment described previously were used. Stand, plot size, and slope were uniform; only the size of the trees, vegetative development, and berries per cluster, which naturally vary with yield, were different. Pounds of berries picked per hour and total yield for each of 128 plots were determined. Efficiency of picking improved sufficiently with yields, increasing by about 25 percent as yields rose from about 300 to 2,000 pounds of market coffee per acre.

SUMMARY

Intensive management practices for the production of coffee are recommended in this bulletin. Their application on suitable lands have resulted in highly profitable yields of approximately 1,500 pounds of high-quality market coffee per acre.

The recommended practices may be summarized as follows:

- Use superior, high-yielding varieties of coffee.

- Plant the trees close together in contour rows.

- Grow them in strong sunlight.

- Fertilize them heavily with a fertilizer high in nitrogen and potash, and apply lime and minor elements as required.

- Spray the trees periodically to control insects and diseases.

- Develop trees with several vertical stems of different ages and prune in rotation.

- Protect the soil against erosion.

- Process coffee carefully with proper, modern equipment.

It is emphasized that plantations must be rapidly converted to intensive culture, that all practices must be properly carried out in a coordinated manner, and that high-yielding coffee requires constant care.

